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STRENGTHENING OF REINFORCED CONCRETE SLABS BY THIN STEEL PLATES GLUED WITH EPOXY

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SUMMARY

It may be necessary to augment the resistance of existing structures due to several reasons. A detective structure may exhibit sings of weakness or damage because of poor desing or inadequate manufacture. Similarly, the structural system may require modifications because the function of the building may have undergone changes.

There are many methods for repair and strengthening. The reason for preferring this specific method of strengthening is its relative low cost. The choice of the breadth and the thickness of the steel plates is therefore of prime importance. A total of ten samples was tested for this study.

The experimental results obtained so far were compared with theory in the hope that a method can be developed for the use of glued steel plates to strengthen reinforced concrete slabs.

I. INTRODUCTION

Buildings in current use may determinate structurally in course of time; or certain elements of a structure may have deficiencies that may have deficiencies that may bring about damage. Repair and strengthening of structural members is a relatively new area of activity in civil engineering where systematic study is now being undertaken. The efficiency of strengthening operations is highly dependent on proper application. The determination of the efficiency is done loungehy by referring to past experience on the behaviour of such structures ,as well as engineering judgement. In fact, one needs as much information on the response of materials and structural members as possible in order to pass judgement on the safe strengthening and repair of structures. Such information is either accumulated by experimental results or as a consequence of damage caused by earthquake on the existing structures. Needless to say, both evidences one required urgently.

The initial phase of the testing program was implemented by loading to failure non-strengthened reinforced concrete slabs in order to establish data for subsequent comparison.

Among the several methods currently used for strengthening damaged slabs, gluing a steel plate on the underside of the slab using epoxy resin. This method has been applied in several public buildings after the earthquakes of Erzincan and Dinar. Experimental work has been carried out of the University of Sheffield [1], [2], [3] to determine the load capacity, deformation, crack propagation and rupture resistance of the external surface such members and a wealth of data has been published.

An analytical model was developed by the University of Cardiff [4] which performs an elastic analysis of interaction between a reinforced concrete beam and epoxy glued steel plate.

The bending resistance of reinforced concrete beams strengthened with steel plates were investigated of King Fahd University [5]. The deflexion of the midpoint of the beams with varying length and thicknesses were measured and analysed.

The most important advantage of strengthening of beams and slabs by gluing of thin steel plates on the underside by epoxy resin is the ease of application even in structures currently in use. The low resistance of epoxy resin to fire, on the other hand, appears to be a serious handicap for the method. In addition, it is found that the combined action improves with the quality of the concrete.

II. FLOOR SLABS GLUED WITH EPOXY

This study had adopted the findings of the King Fahd University [6] and Cardiff University [7], [8], [9] to dimension the strengthened beams. The calculation of the beams strengthened by steel plates is performed in three stages. Initially, a relationship between the reinforcement and the steel plate is established for the formation of a ductile crack. A comparison is done the location of the maximum stress points between the beam and the plate and a check whether the bending of the plate is within acceptable limits in the second phase. The thin and the final phase is the investigation of the shearing resistance of the beams.

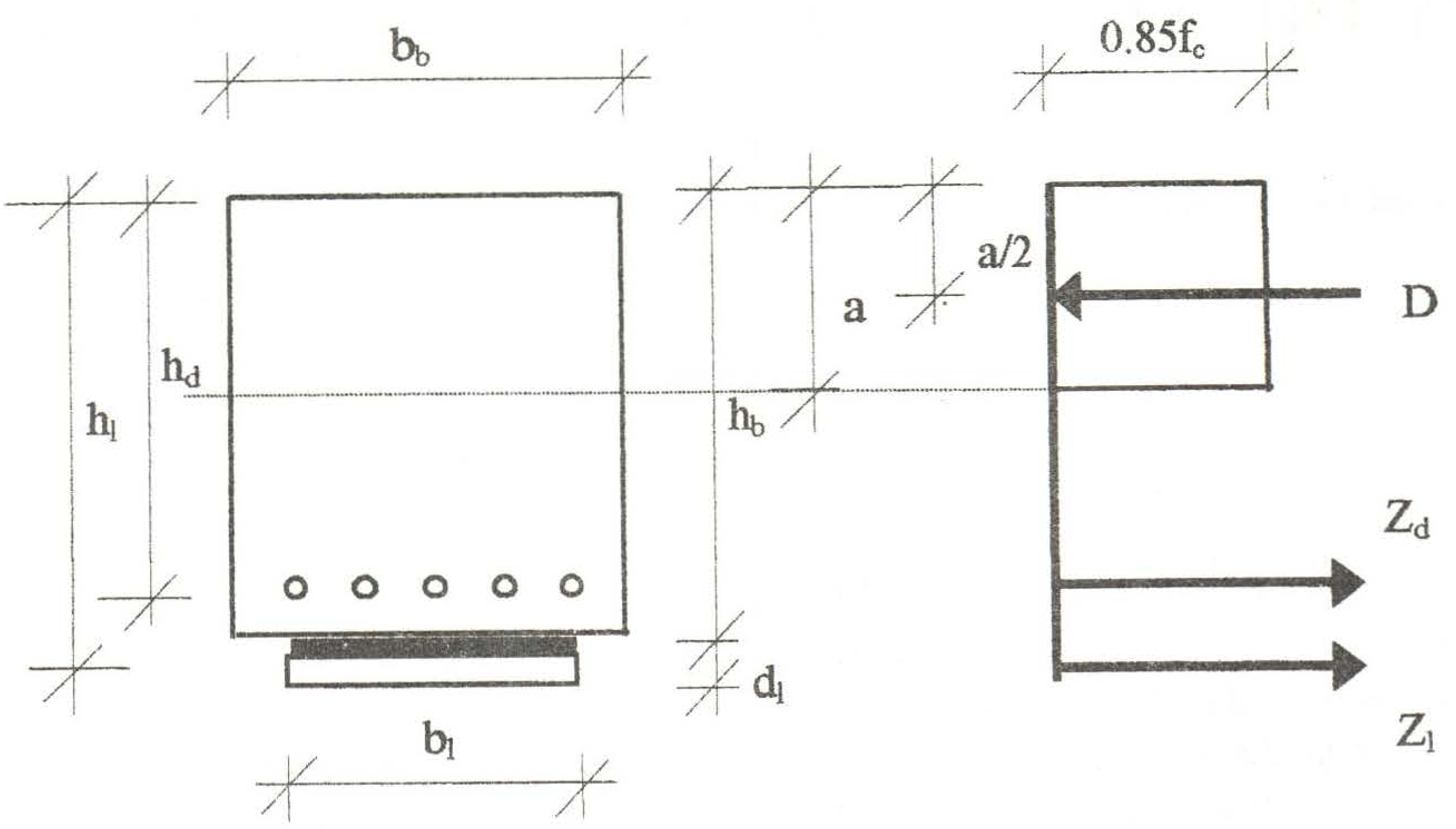

Figure 1. Ultimate forced acting on plated beam section

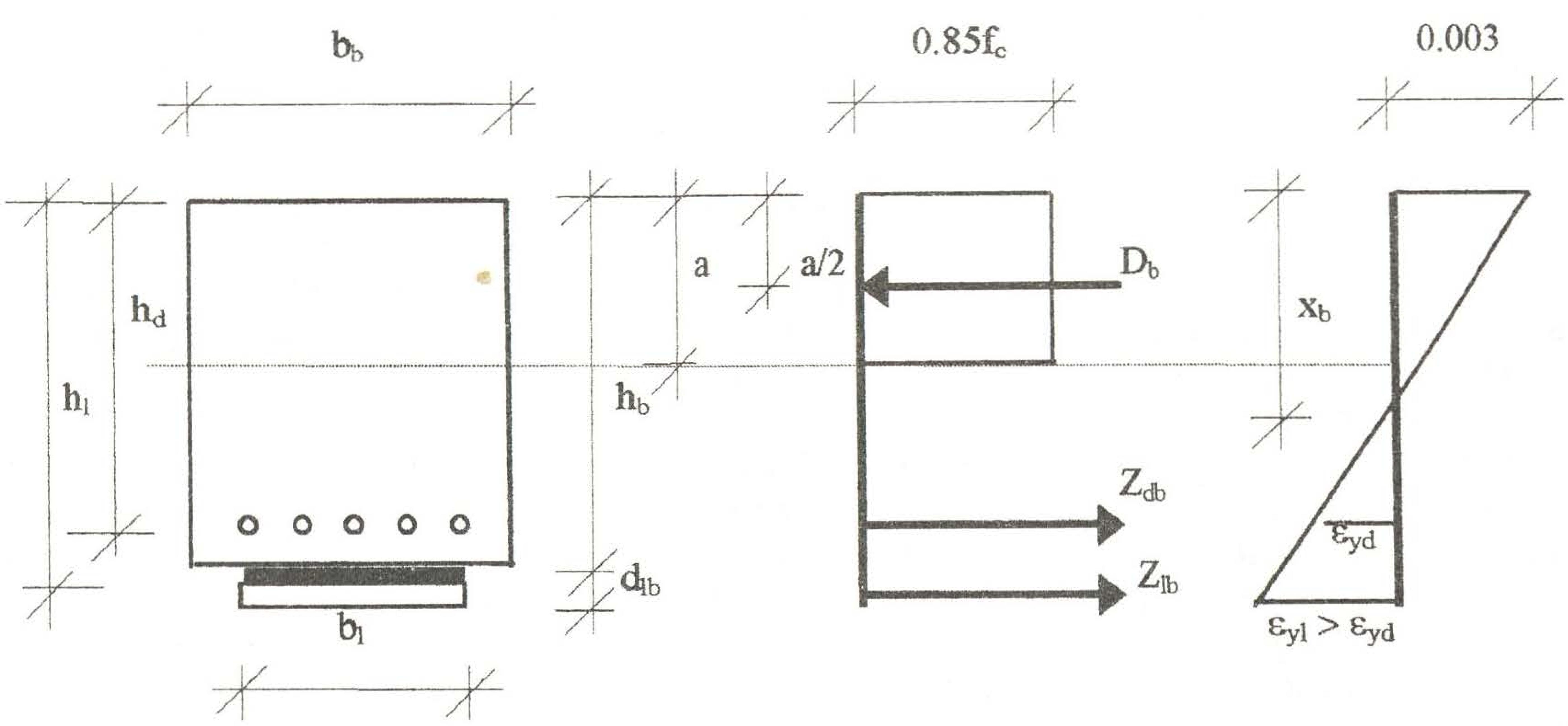

Figure 2. Condition of balanced loads

Step 1: Flexural desing

The condition of equilibrium requires ,

$$Z_d\left(h_d-\frac{a}{2}\right)+Z_l\left(h_l-\frac{a}{2}\right)=\frac{M_u}{\phi} \quad (1)$$

$Z_d = F_d.f_{yd}$ represent force taken by the beam reinforcement, $Z_l = F_l.f_{yl}$ force carried by the steel plate, M_u the maximum moment, h_b the distance between the axis of the plate and top of the beam, h_l the distance between the top of the beam and the rebars.

The depth of the reinforced concrete section is found as,

$$a=\frac{\left[F_d.f_{yd}+b_l.d_l.f_{yl}\right]}{0.85f_c.b_b} \quad (2)$$

Here: f_c (The compressive strength of concrete), b_b (Width of concrete beam), f_{yd} and f_{yl} (Yield stress of rebar and yield stress of steel plate), b_l and d_l (Breadth and thickness of the steel plate).

Sowing equations (1) and (2)respectively,

$$F_1.d_l^2+F_2.d_l+F_3=0 \quad (3)$$

The F coefficient are determined as,

$$F_1=\frac{b_l.f_{yl}}{2}\left[1-\frac{b_l.f_{yl}}{0.85f_c.b_b}\right] \quad (4)$$

$$F_2=b_l.f_{yl}\left[h_b+d_b-\frac{F_d.f_{yd}}{0.85f_c.b_b}\right] \quad (5)$$

$$F_3=\left\{F_d.f_{yd}\left[d_l-\frac{F_d.f_{yd}}{2(0.85)f_c.b_b}\right]-\frac{M_u}{\phi}\right\}$$
(6)

Here, d_l (the depth of steel strengthening element), d_b (depth of concrete section).

The thickness of steel plate is determined as,

$$d_l=\frac{-F_2+\sqrt{F_2^2-4F_1.F_3}}{2F_1}\le d_{lb} \quad (7)$$

Here, d_{lb} shows the thickness of the plate at equilibrium conditions, which is also equal to the maximum plate thickness where by a ductile bending crack can be formed. The condition of balanced load is reached at a stage where of the concrete fibers have reached the crushing stress thus causing the strengthening element reaches yield stress.

Step 2 : Plate - concrete interface stresses

The rigidity against shear K_k, and the normal stress in wit length of epoxy resin can be expressed K_n,

$$K_k=\frac{G_a.b_a}{d_a} \quad (8)$$

$$K_n=\frac{E_a.b_a}{d_a} \quad (9)$$

The symbols in these equations G_a, b_a, d_a, E_a are the shear modulus width, thickness and modulus of elasticity of the epoxy, respectively.

The maximum value of shear stress along the interface is,

$$\tau_{xy}=\left[V+\left(\sqrt{\frac{K_k}{E_l.b_l.d_l}}\right)M\right]\frac{(b_l.d_l)(h_l\quad h)}{I.b_a} \quad (10)$$

Here, E_l, b_l, d_l are the modulus of elasticity, width and the thickness of steel strengthening plate.

The maximum value of normal stress in the interface at ends of the plate is,

$$\sigma_x=\tau_{xy}.d_l\sqrt[4]{\frac{K_n}{4E_l.I_l}} \quad (11)$$

The values of M, V, I_l used in the equation (11) are defined as,

$$M=\left(\frac{P}{2}\right)\left[L_0+\left(\frac{d_b+d_l}{2}\right)\right] \quad (12)$$

$$V=\frac{P}{2} \quad (13)$$

$$I_1 = \frac{b_1.d_1^3}{12} \quad (14)$$

The L_0 defined here is the distance from the end of the slab to the support point.

The height of the neutral axis is obtained as,

$$h = \left[\frac{-B + \sqrt{B^2 + 4A.C}}{2A}\right] \quad (15)$$

where,

$$A = \frac{E_b.b_b}{2E_1} \quad (16)$$

$$B = F_d + b_1.d_1 \quad , \quad C = h_d.F_d + h_1.b_1.d_1 \quad (17)$$

The moment of inertia of the model beam, assumed to behave as a composite materials is expressed as,

$$I = \frac{E_b.b_b.h^3}{3E_1} + F_d(h_d - h)^2 + b_1.d_1.(h_1 - h)^2 \quad (18)$$

The values of stresses σ_x and τ_{xy} are calculated for different values of the width of the plate L_0.

Step 3 : Shear capacity of plated beams

The shearing capacity of a beam strengthened by a steel plate in given as,

$$V_{ul} = V_b + k.V_d \quad (19)$$

Where,

$$V_b = \frac{\left[\sqrt{f_c} + 100\rho_w\left(\frac{V_u.d}{M_u}\right)\right]}{6}.b_w.d \quad (20)$$

$$V_d = \frac{F_w.f_{ydt}.d}{s} \quad , \quad k = 2{,}4e^n \quad (21)$$

The definition of the variables are given as,

$$n = -0.08C_{R1}.C_{R2}.10^6 \quad (22)$$

$$\frac{V_u.d}{M_u} = 1 \quad (23)$$

$$C_{R1} = \left[1 + \left(\sqrt{\frac{K_d}{E_1.b_1.d_d}}\right).a^*\right]\frac{b_1.d_d}{I.b_a}(h_1 - h) \quad (24)$$

$$C_{R2} = d_d.\sqrt[4]{\frac{K_n}{4E_1.I_p}} \quad (25)$$

ρ_w	main steel reinforcement ratio
b_w, d	width and effective depth unplated reinforced concrete section
V_d	amount of shear reinforcement
f_{ydt}	stirrup yield strength
s	stirrup spaning
a^*	M_0/V_0 at plate cutoff location
I	second moment of area of equivalent transformed steel section about neutral axis for cracked section

$K_d = G_a \frac{b_a}{d_a}$ shear stiffness of interface layer

G_a, b_a, d_a	shear modulus, width and depth of adhesive
I_p	second moment of area of steel plate about its own centroid

$K_n = E_a \frac{b_a}{d_a}$ normal stiffness of interface laye

E_a	elastic modulus of adhesive

III. REPAIR AND STRENGTHENING BY THE USE OF EPOXY RESIN

Epoxy resins are synthetic materials with excellent gluing properties due to their polar and ester contents. Many varieties of the epoxy are manufactured depending on the chemical characteristics structure an purpose of use. Consequently epoxy cements have found wide use in the repair and strengthening of reinforced concrete curtains, columns, slabs and beams. Investigations into their properties have shown that a high level of adhesion is attained, minimal shrinkage during curing, a wide range of temperatures during cure, and possibility of providing immediate service after application.

There are four kinds of epoxies :epoxy resin, polyurethanes, polyesters and acrylics. Epoxies appear to have found most frequent use.

The basic properties of the resin used to glue concrete and steel plate are: 20 N/mm^2 adhesion to concrete, 3,5 N/mm^2 adhesion to steel, a compressive strength of 65 N/mm^2, tensile strength of 20 N/mm^2.

IV. EXPERIMENTAL WORK

The size of the reinforced concrete member chosen for this study is 3000.800.100 mm as detailed in Figure 3, and a steel plate to match.

The steel plate is glued underneath the beam to provide are economical solution. Initially steel plate widths of 500 mm and 600 mm were tested. In the second phase, the thickness of the steel plates were chosen as 2 mm and 4 mm with the aim of finding the most suitable size of the steel plate for the beam size adapted. The number of tests total 10 (Figure 4).

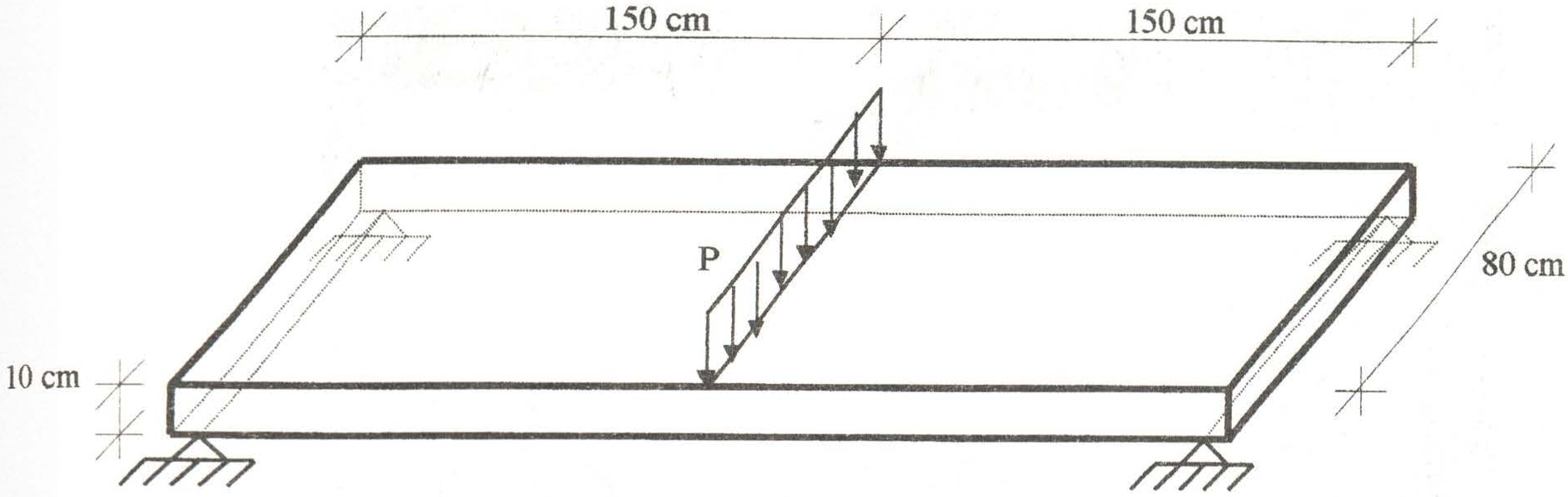

Figure 3. Type of Loading and Supports for the Reinforced Concrete Slab

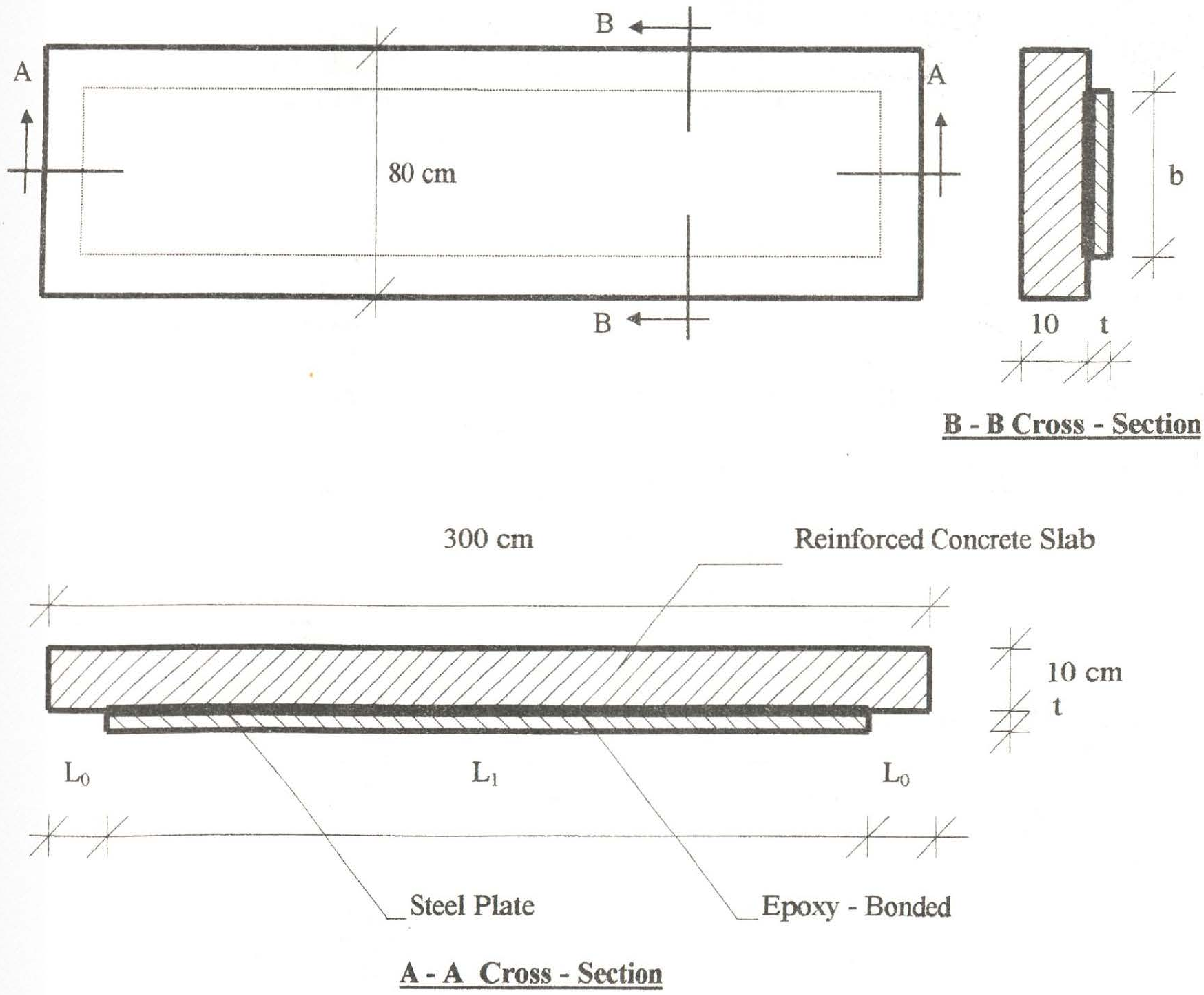

Figure 4. Strengthening of reinforced concrete Slab by thin steel plates glued with epoxy

V. RESULTS OF TESTING

The tests were carried of the Structures Laboratory of Sakarya University, using the loading frame of 200 kN capacity (Hi-Tech Magnus). The loading arrangement is shown in Figure 5 where free supported beams with the steel plates glued underneath were loaded of the centerline with a line load (Figure 6).

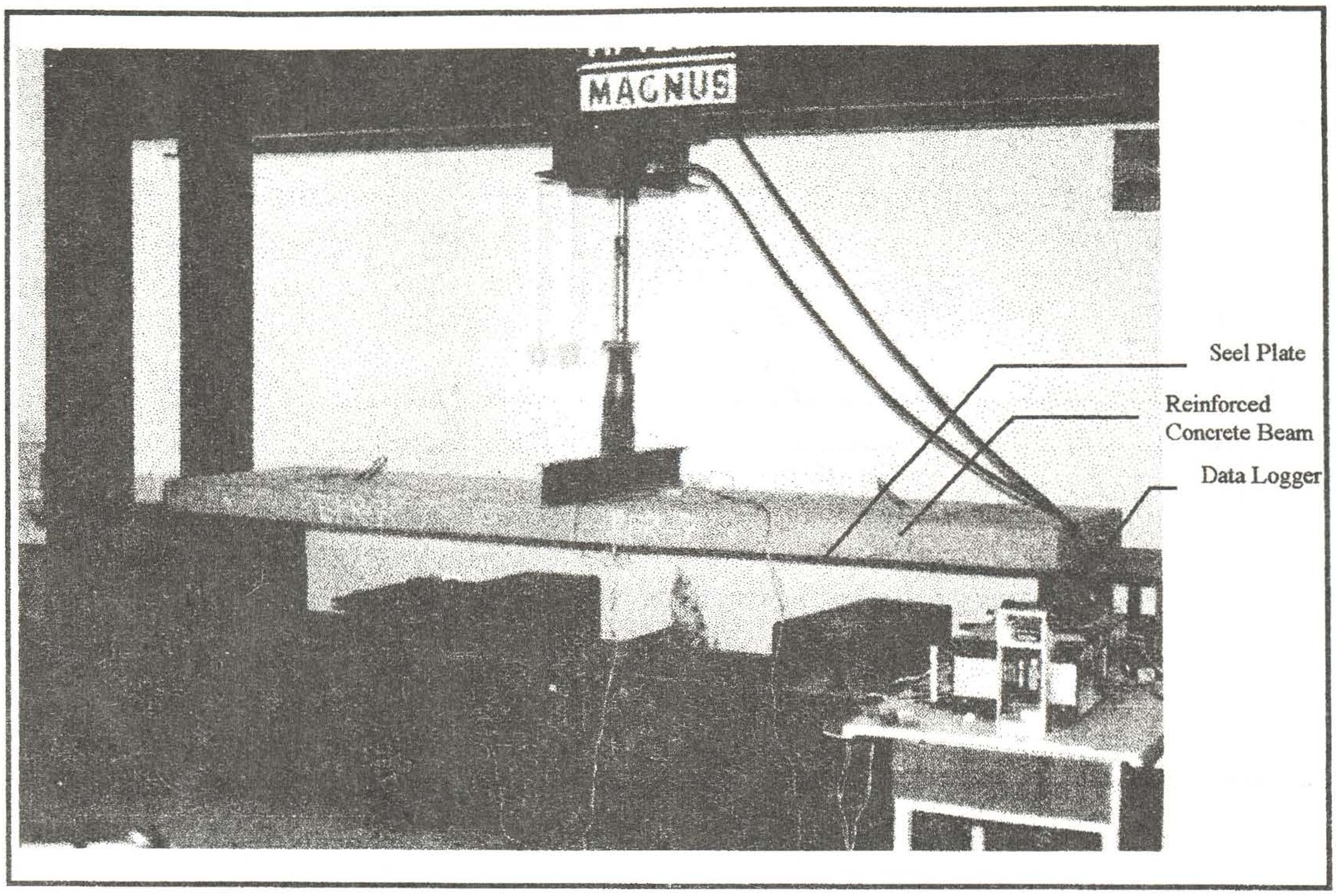

Figure 5. Test Frame (Photography)

A total of eight samples were loaded to failure as summarized in Table 1. The testing arrangement and different stages of a test is shown in Figure 6. The load is applied by means of a hydraulic jock, and the deformation of the members by strain gauges of mm width (FLA-3-11) with a resistance of 120 ±0,3 Ω. The gauges are attached of the centerline of the steel plate as well as the midpoint of the compressive zone of the reinforced concrete beam. This way, both the tensile and the compressive strains are recorded, and logged in the concrete and the steel. The deflexion of the beam are measured at the centre by means of a dial gauge of 0,01 mm sensitivity.

The results of this group of testing are summarized in Figure 6 to 22.

Table 1. Results of Testing and Theoretical

Specimen No	Dimension of Beam (mm)	Dimension of Steel Plate (mm)	Length of Plate L_1 (mm)	The Rate of the Concrete	Ultimate Load (Theoretical) (kN)	Ultimate Load (Experimental) (kN)
EPR-1	3000.800.100	-	-	C 30	10	11
EPR-2	3000.800.100	-	-	C 30	10	11,5
EPR-3	3000.800.100	2500.500.2	2500	C 30	35	43
EPR-4	3000.800.100	2500.500.2	2500	C 30	35	43
EPR-5	3000.800.100	2500.600.2	2500	C 30	41	50
EPR-6	3000.800.100	2500.600.2	2500	C 30	41	49
EPR-7	3000.800.100	2400.500.4	2400	C 30	52	58
EPR-8	3000.800.100	2400.500.4	2400	C 30	52	59
EPR-9	3000.800.100	2400.600.4	2400	C 30	61	67
EPR-10	3000.800.100	2400.600.4	2400	C 30	61	68

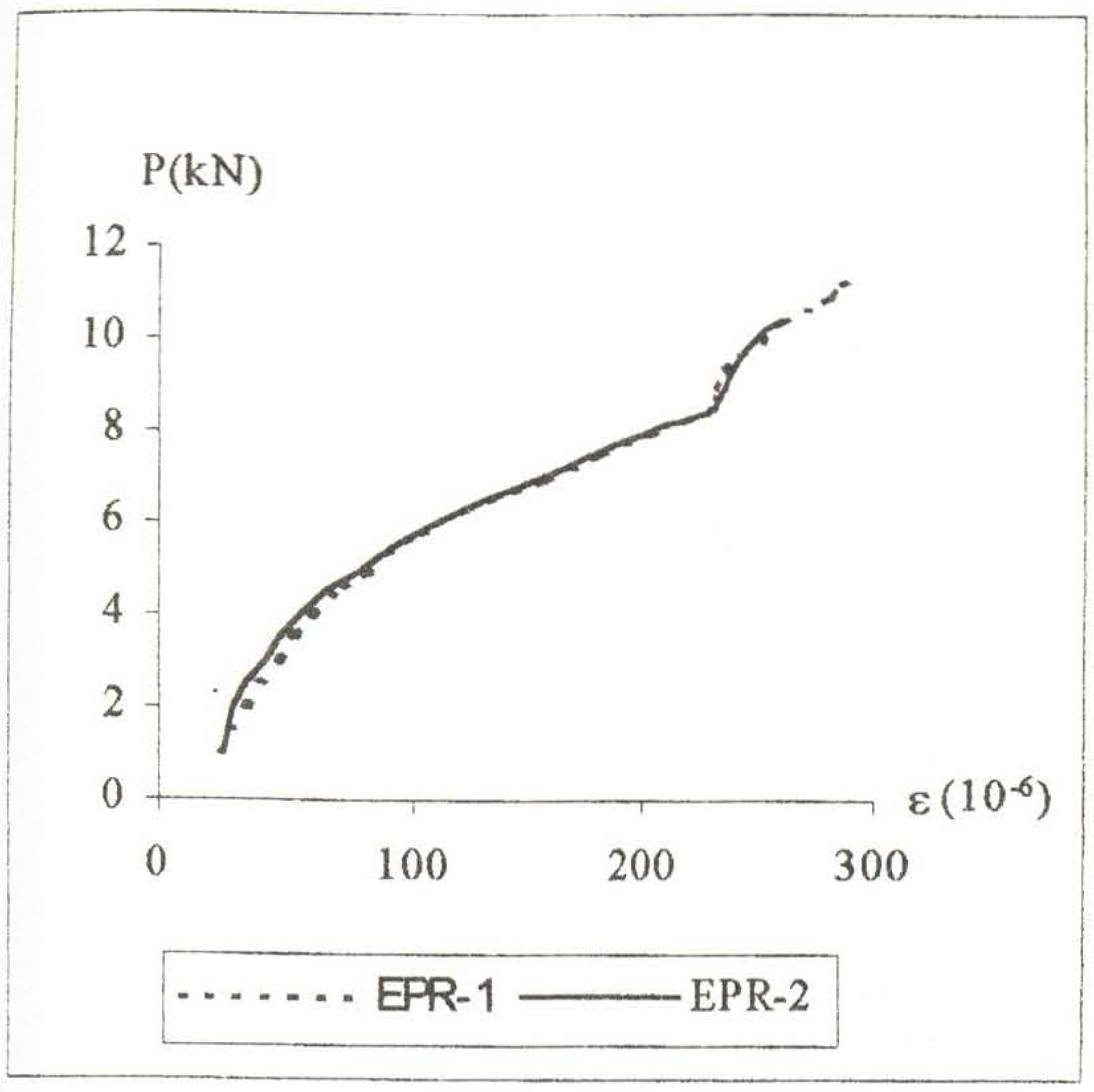

Figure 6. Load - Deformation Diagram

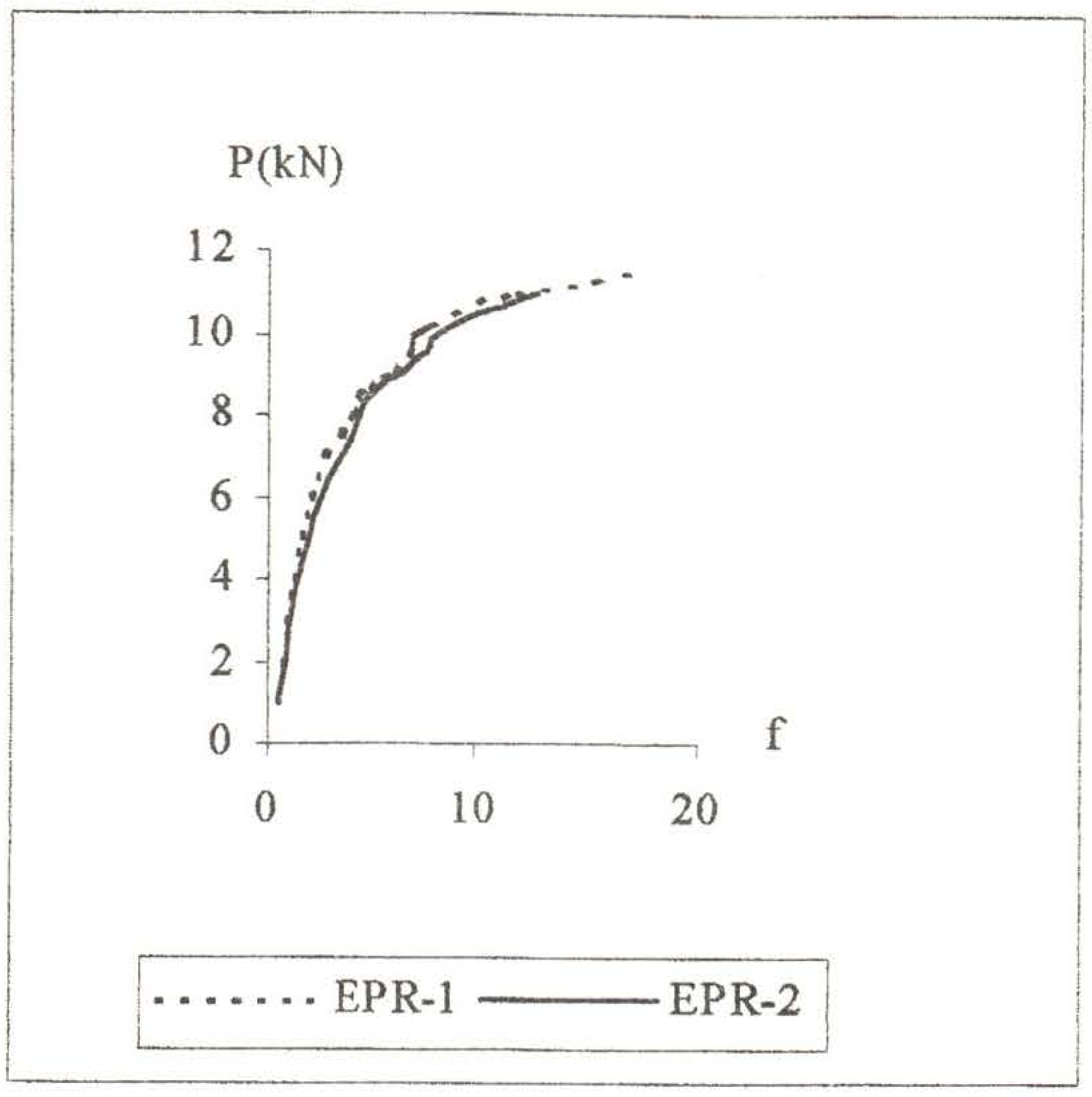

Figure 7. Load - Displacement Diagram

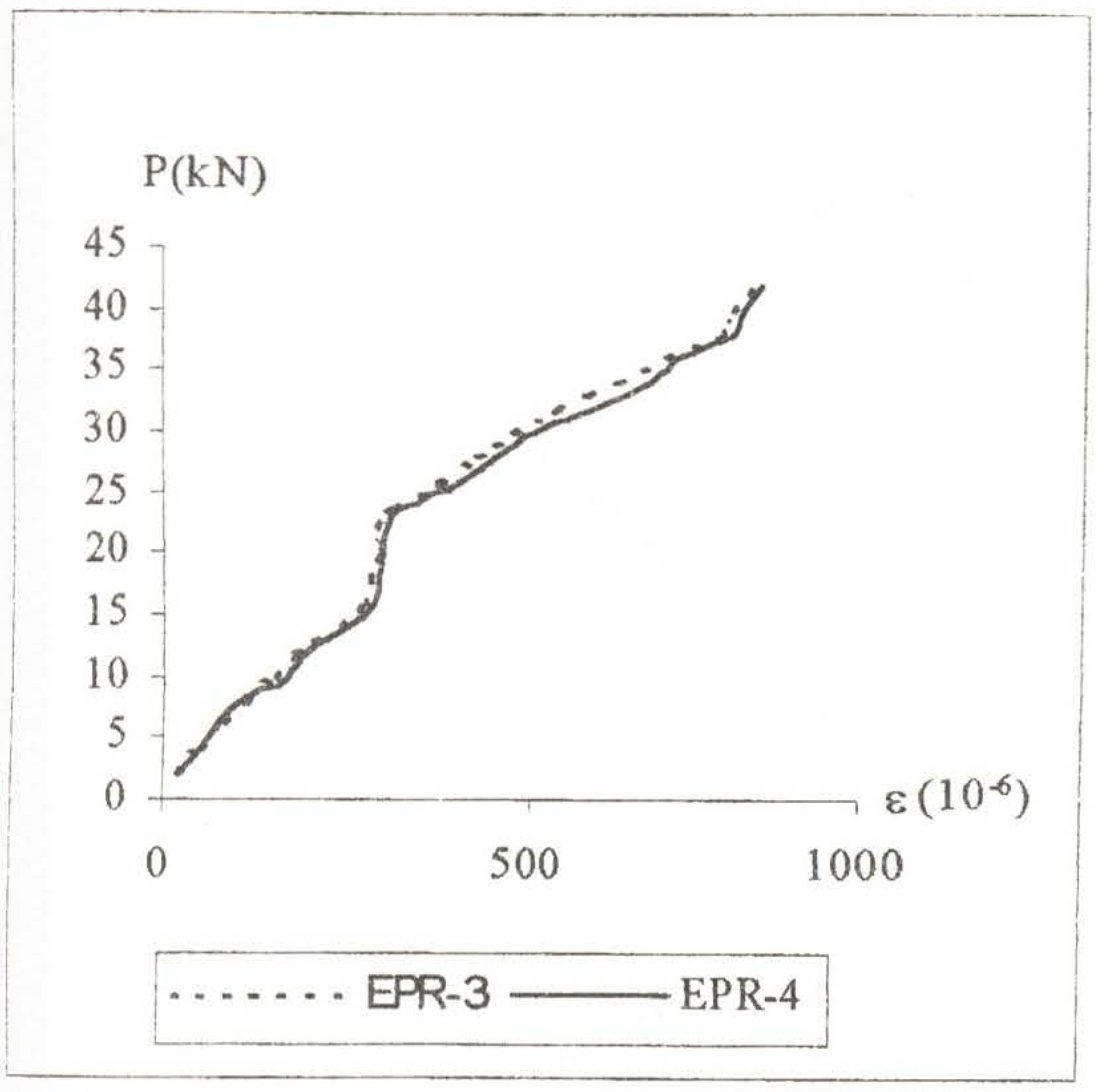

Figure 8. Load - Deformation Diagram (Concrete)

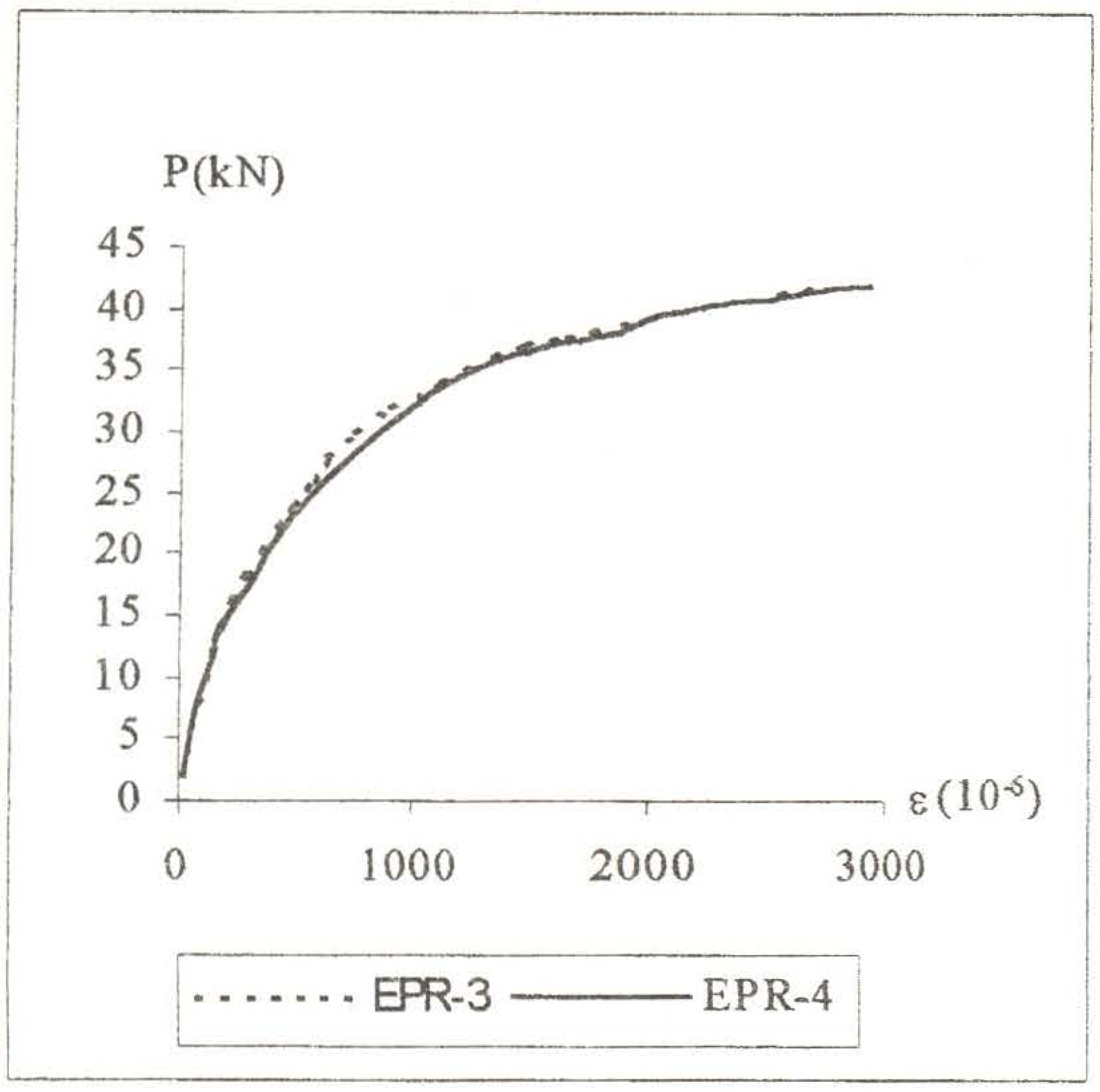

Figure 9. Load - Deformation Diagram (Steel)

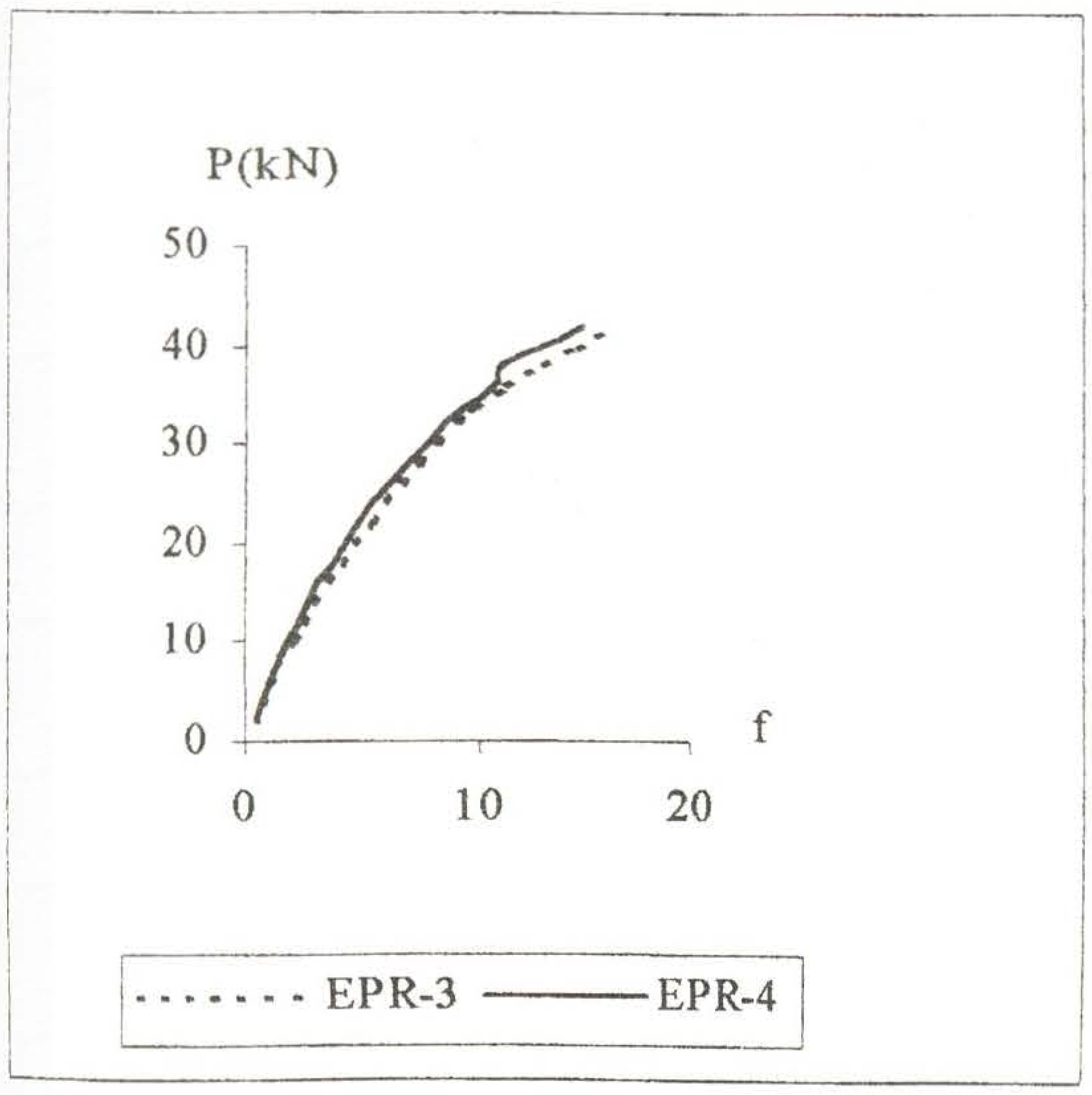

Figure 10. Load - Displacement Diagram

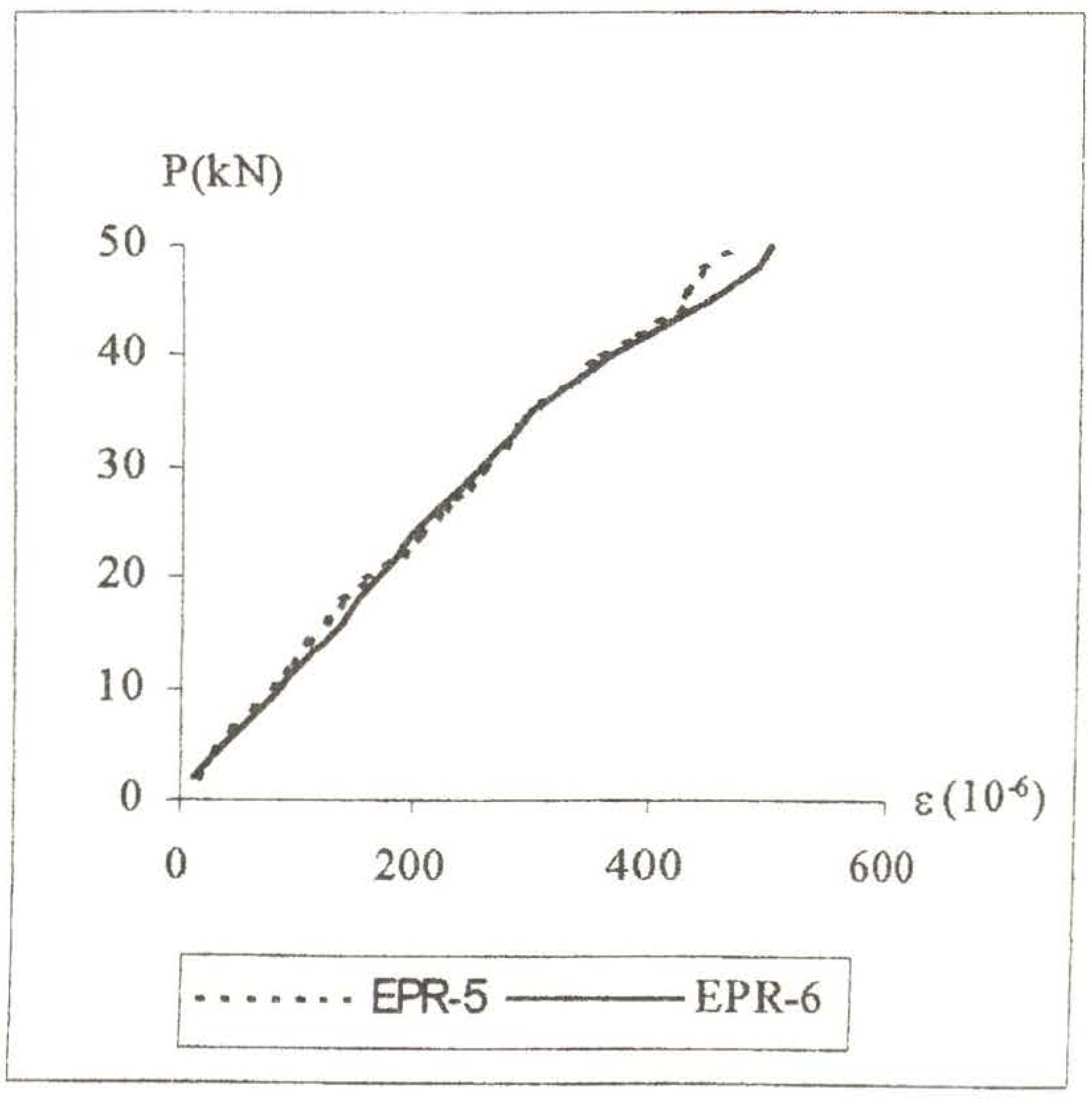

Figure 11. Load - Deformation Diagram (Concrete)

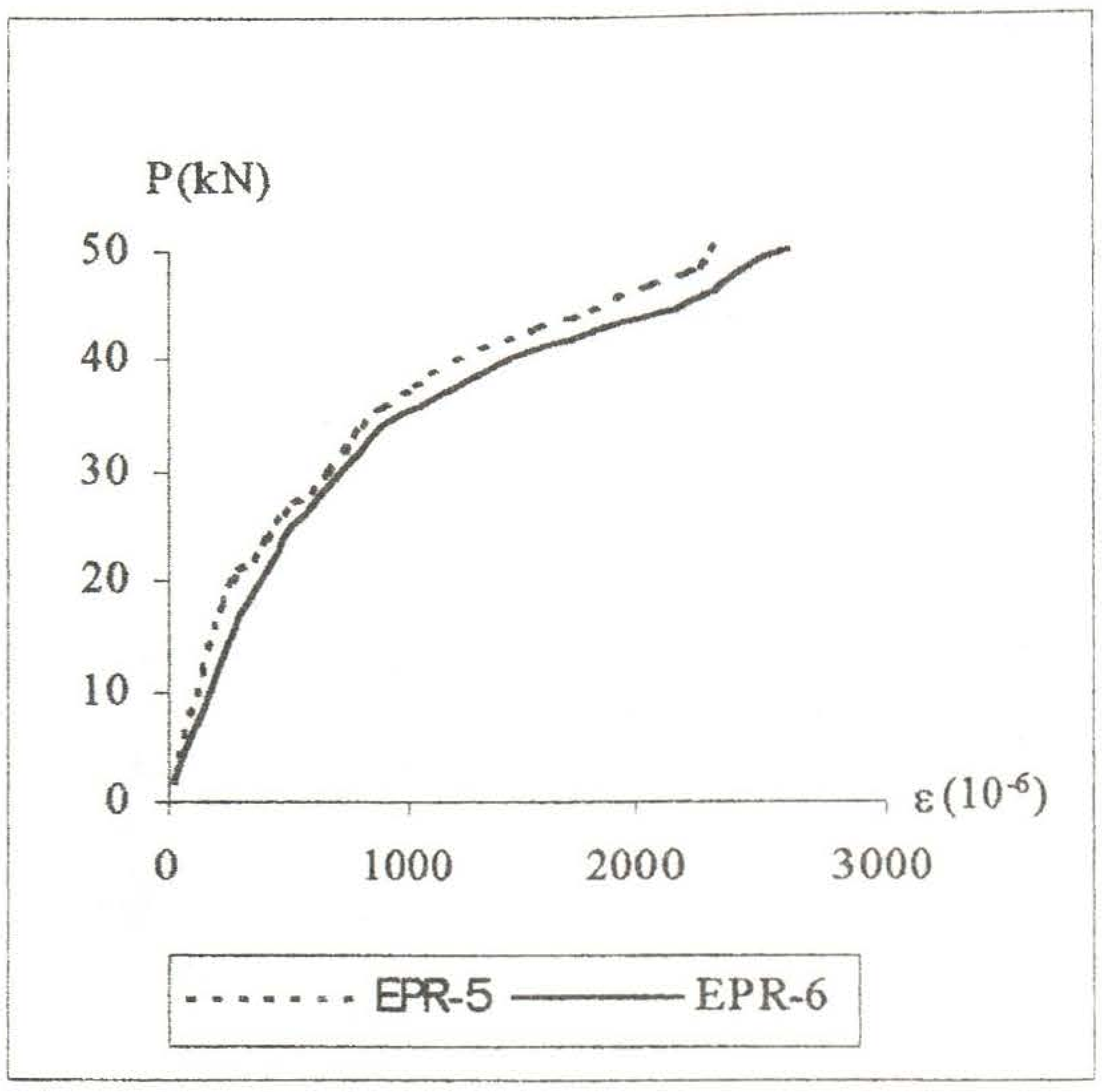

Figure 12. Load - Deformation Diagram (Steel)

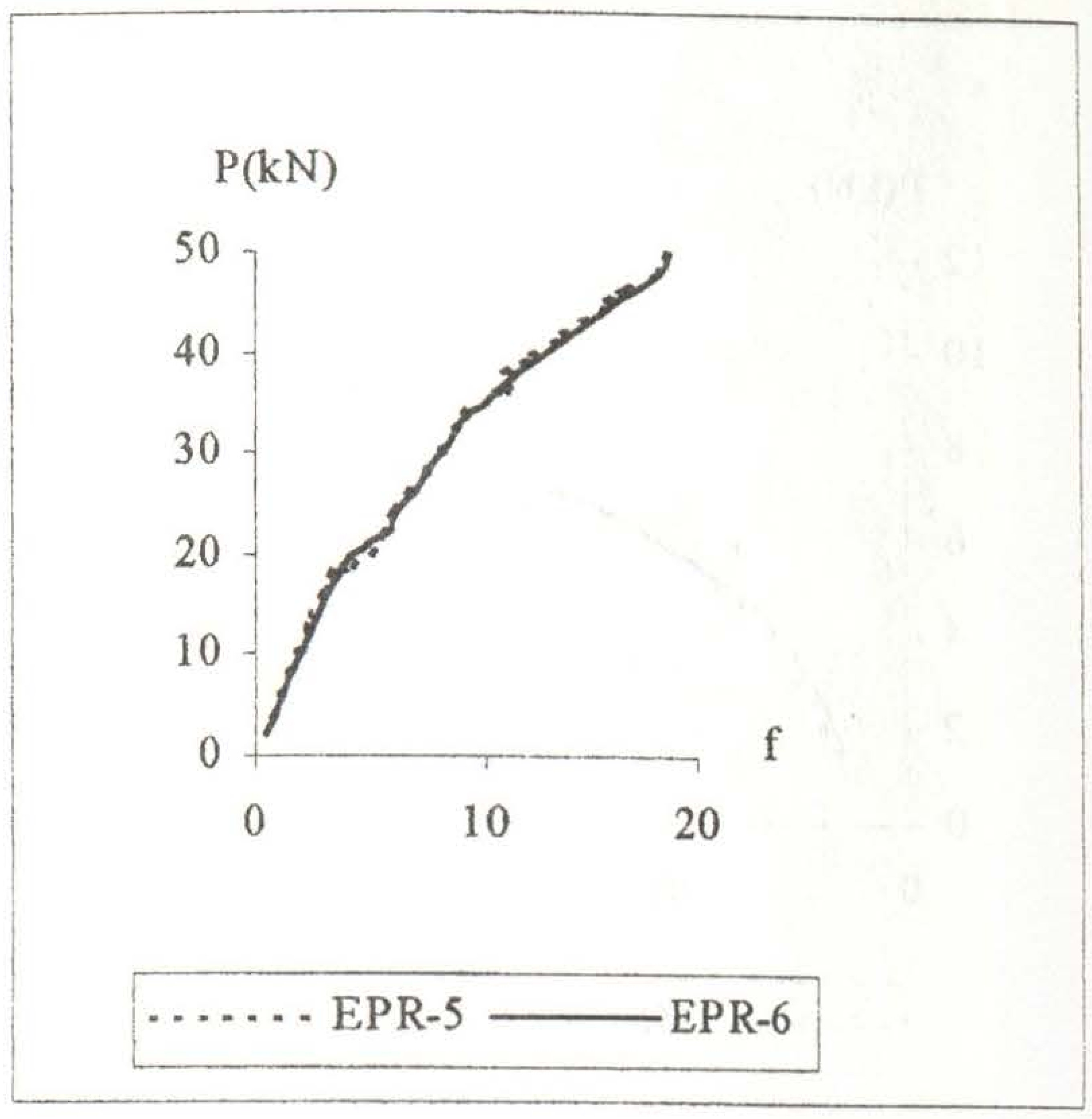

Figure 13. Load - Displacement Diagram

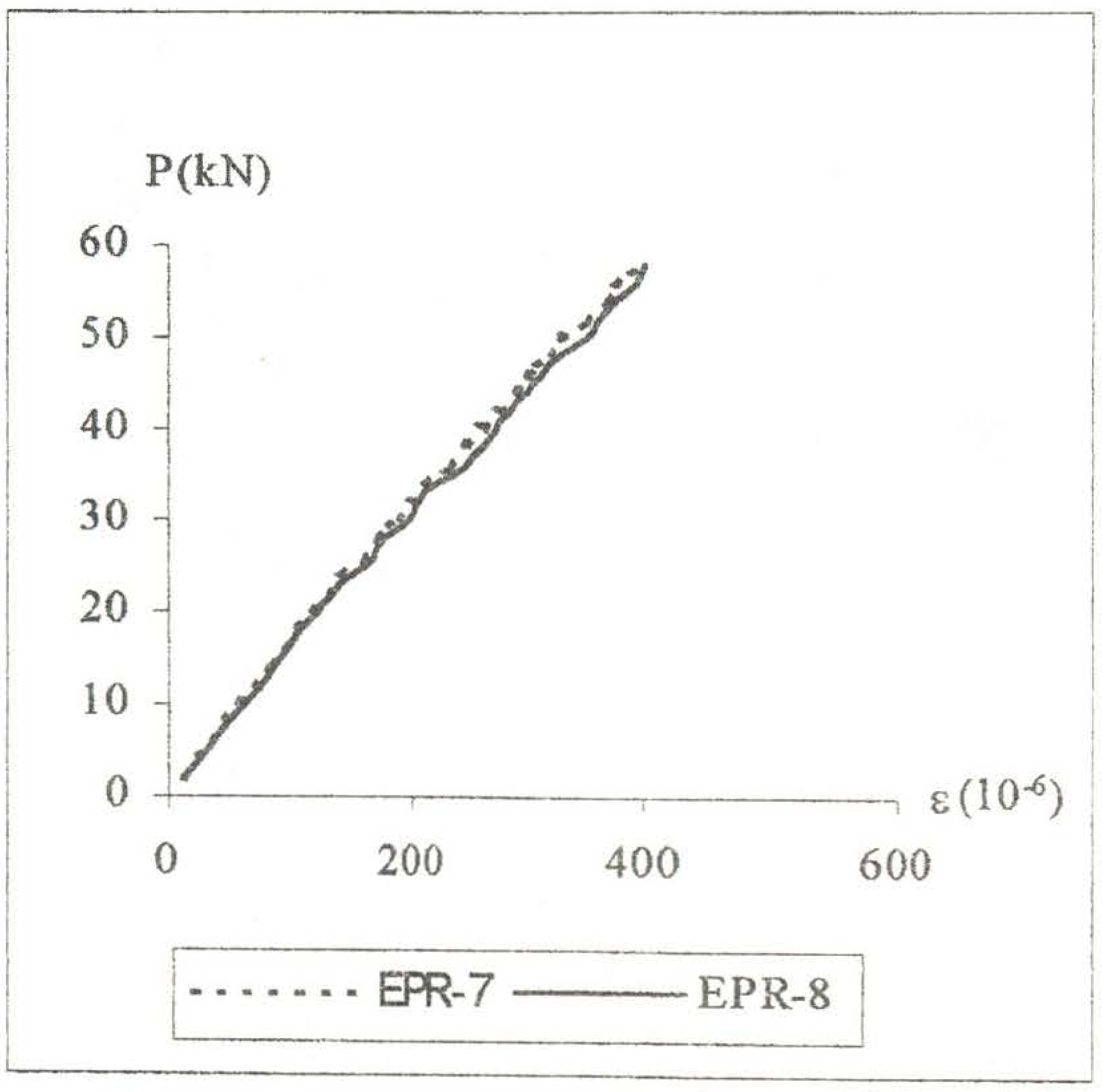

Figure 14. Load - Deformation Diagram (Concrete)

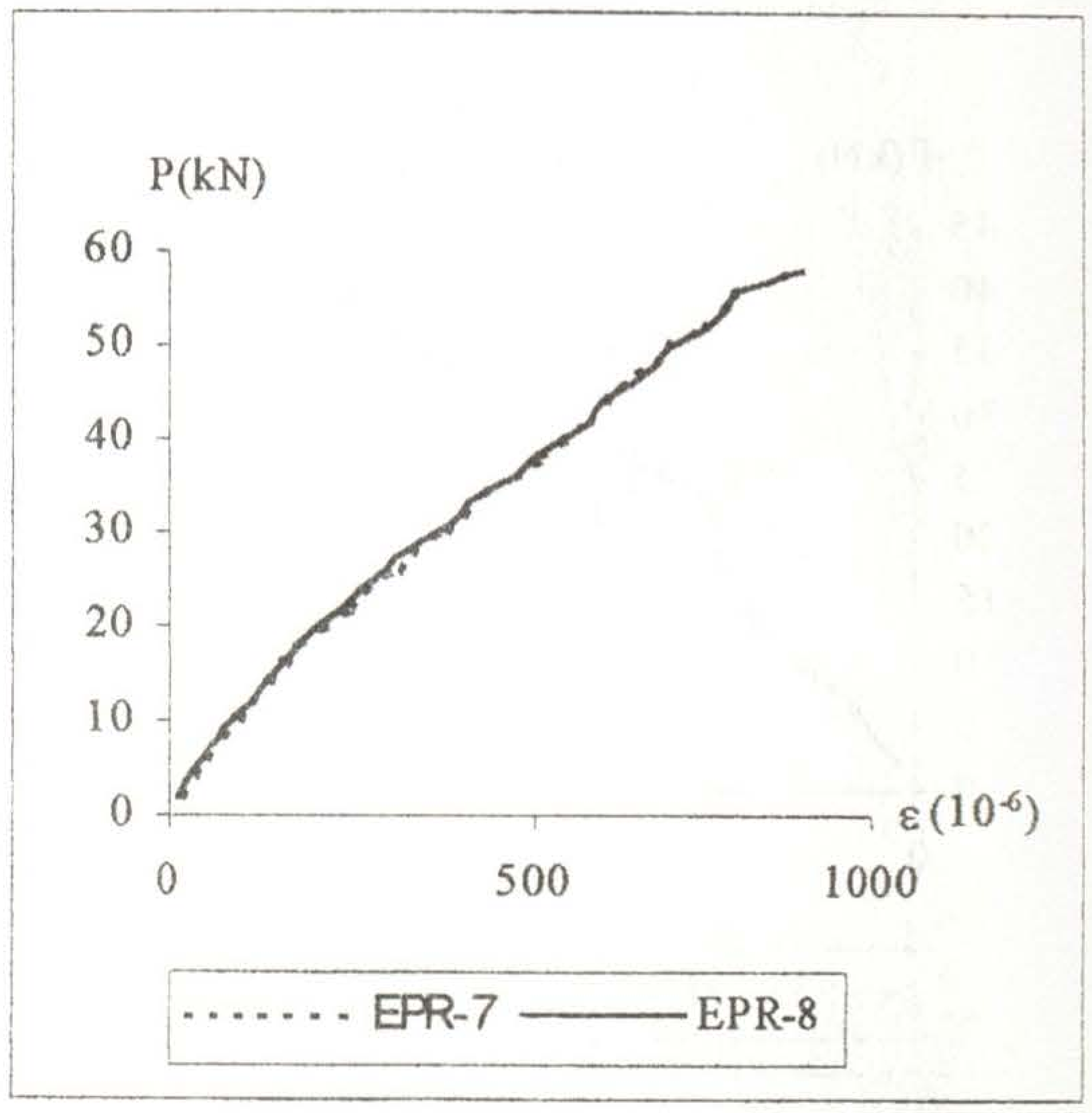

Figure 15. Load - Deformation Diagram (Steel)

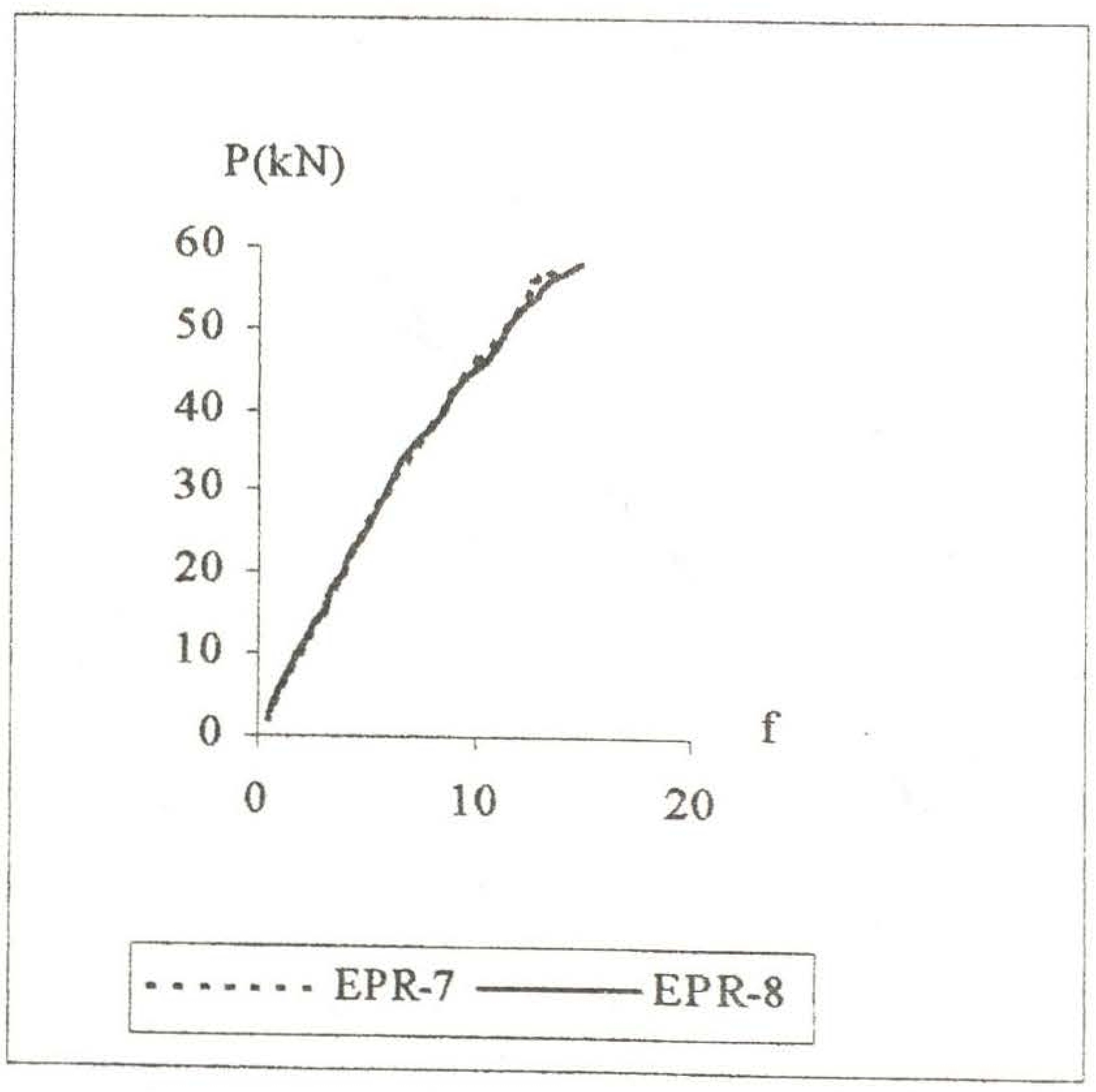

Figure 16. Load - Displacement Diagram

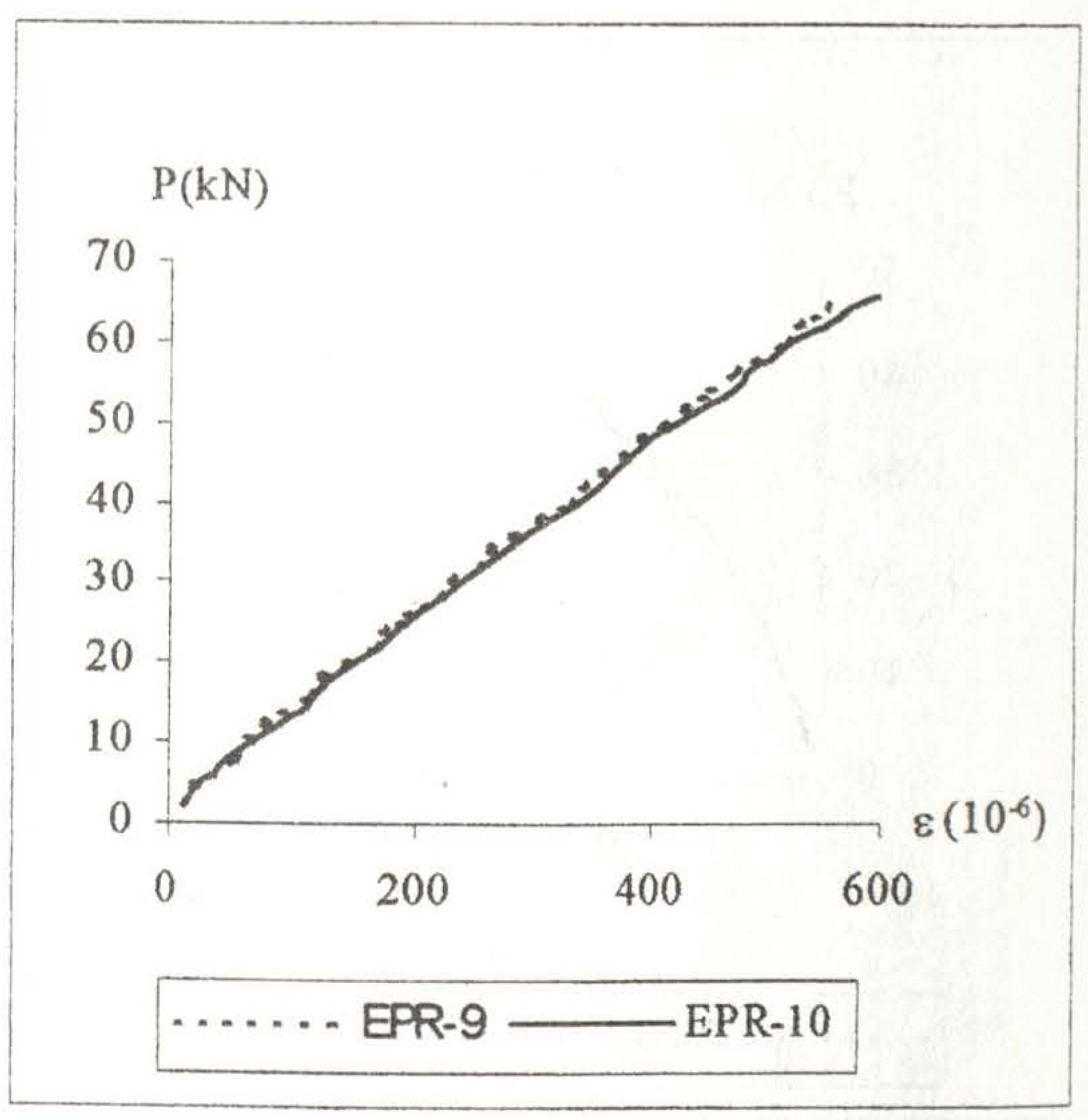

Figure 17. Load - Deformation Diagram (Concrete)

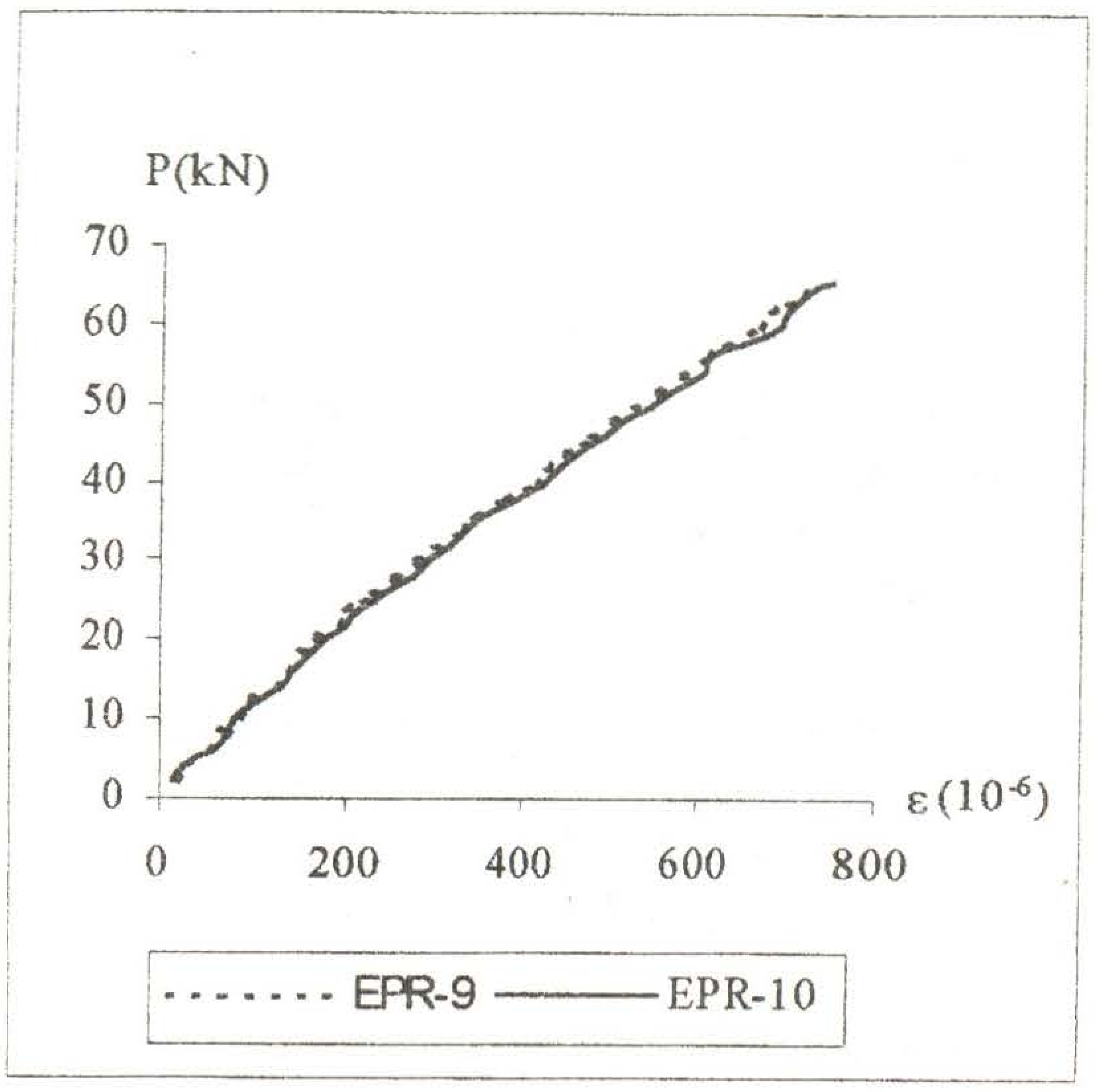

Figure 18. Load - Deformation Diagram (Steel)

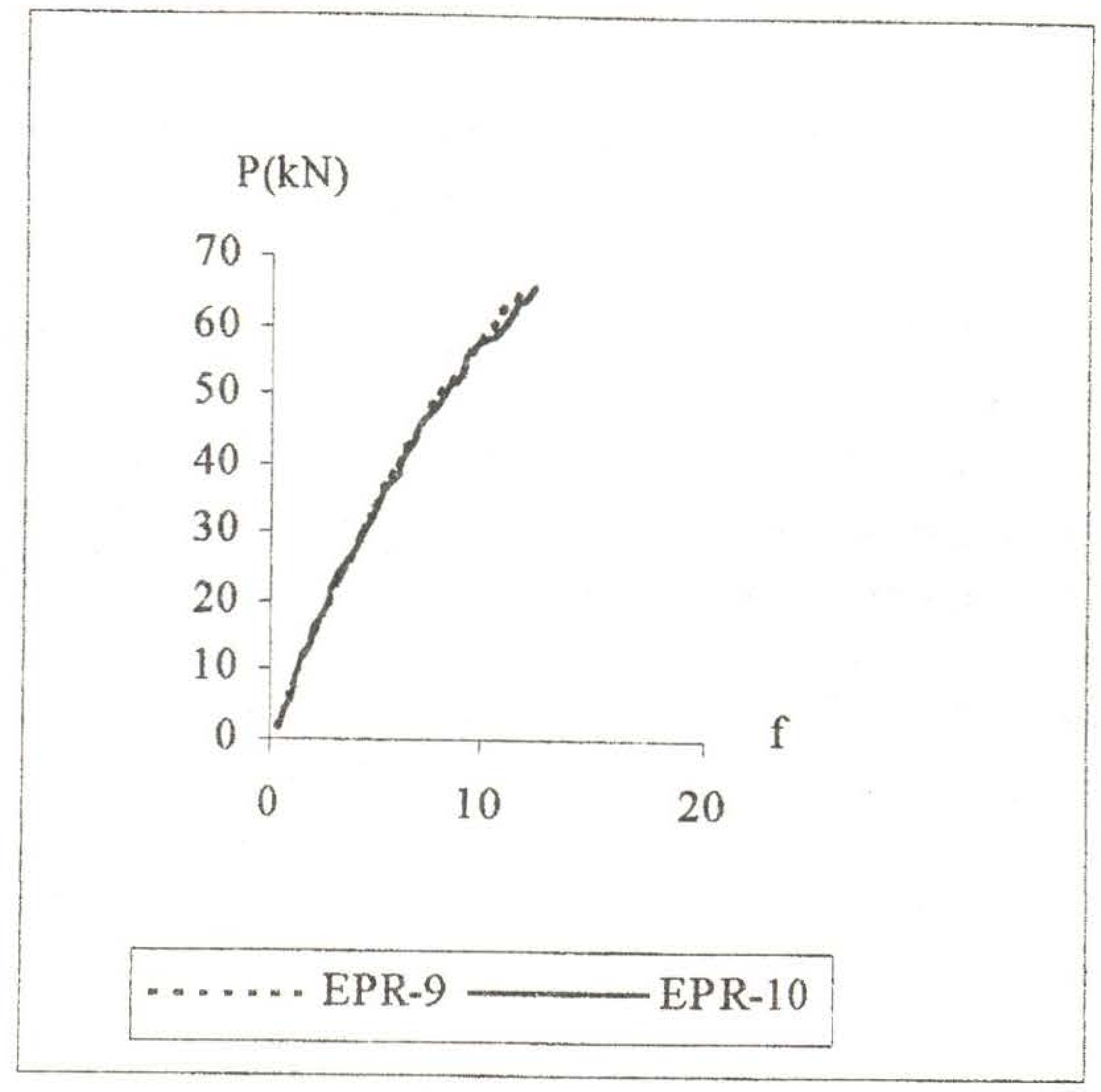

Figure 19. Load - Displacement Diagram

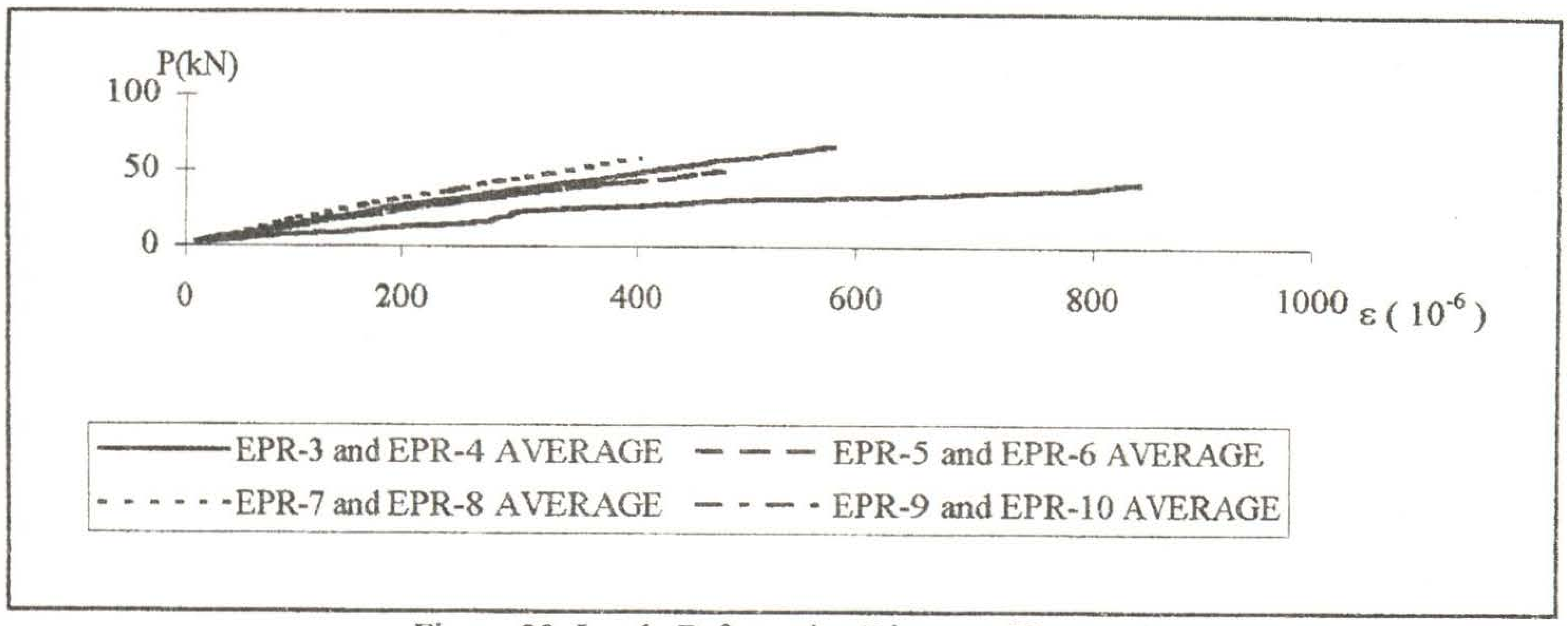

Figure 20. Load - Deformation Diagram (Concrete)

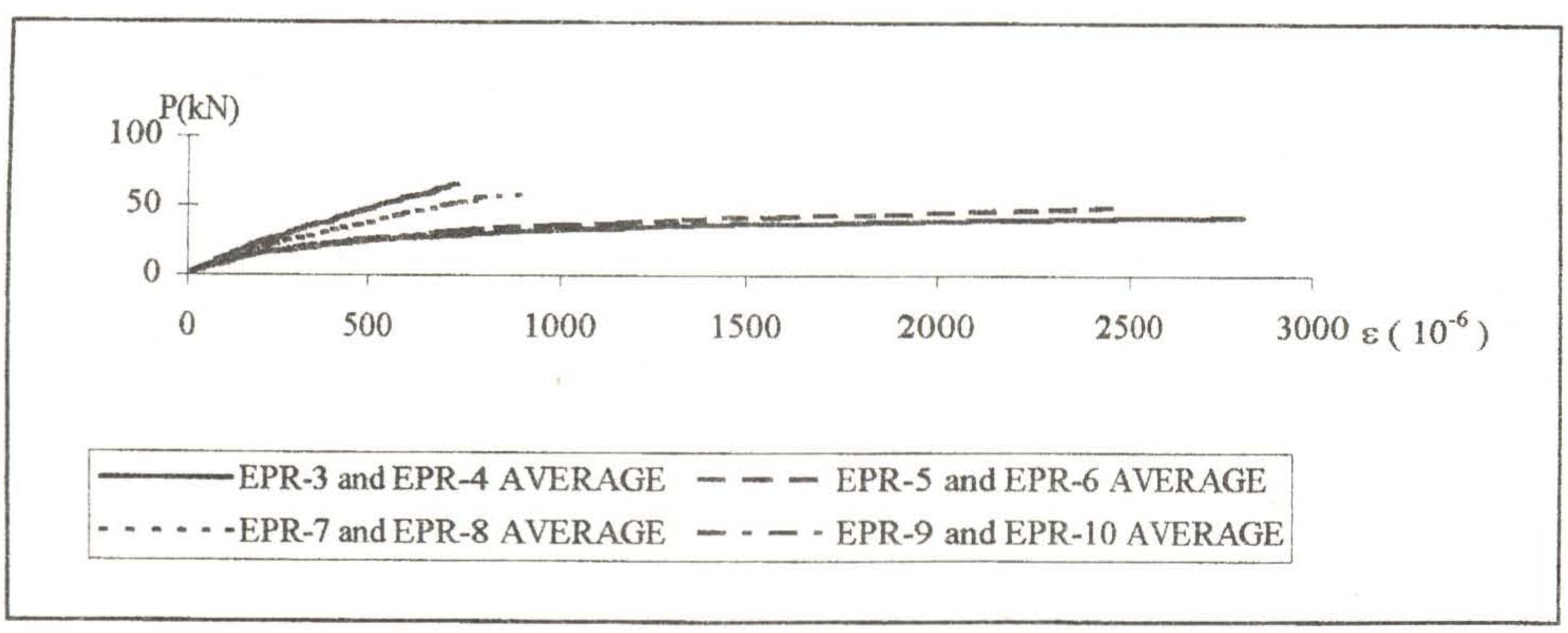

Figure 21. Load - Deformation Diagram (Steel)

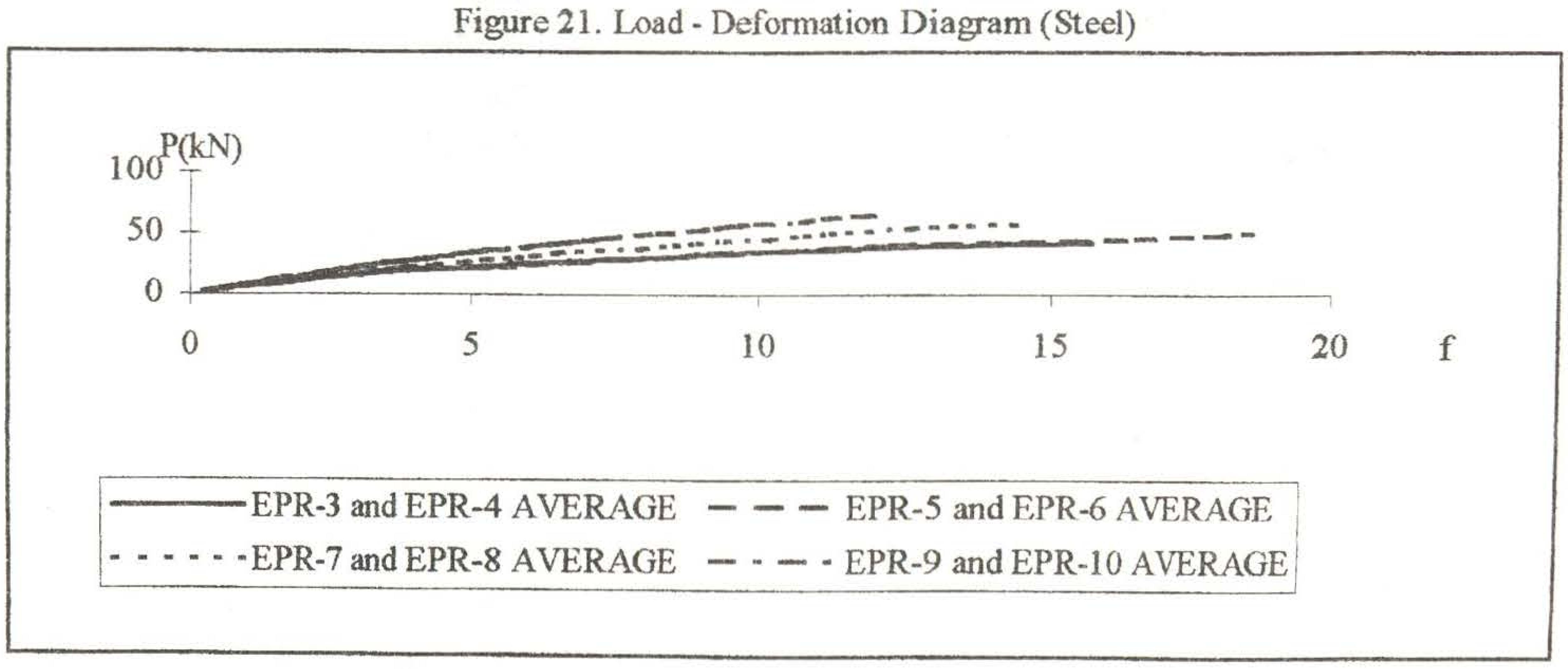

Figure 22. Load - Displacement Diagram (Centre of the Beam)

VI. DISCUSSION OF THE RESULTS AND RECOMMENDATIONS

One of the most important points in strengthening of reinforced concrete beams is desing with regard to economy. The width, thickness and the distance of the steel beam to the supports is therefore critical. Desing is thus implemented in three steps. First step is to find out the influence of the width of the steel plate to the bearing load. The effect of the thickness on the failure load is studies in the support is evaluated last.

The results of ultimate load obtained from experiments are compared with theoretical-results (Table 1).

Initially two unstrengthened reinforced concrete beams were loaded to failure at 11,5 kN. This bearing load was found to increase by about 282 % when the beams were strengthened by steel plates of size 2500.500.2 mm. The load bearing capacity increased by 340 % when plates of 2500.600.2 mm were used. Similarly the bearing load increased 420 % when plates 2400.500.4 mm, whereas an increase of 500 % was recorded for steel plates of 2400.600.4 mm. The obvious result from the data is that using epoxy bonded steel plates to strengthen a reinforced concrete beams is an effective method.

Another finding of the experimental work is that mode of failure for beams strengthened by 2 mm thick steel plates is by searing at ends of the plates. The 4 mm thick plates however failure was reached by bending at midpoint of the beam. Figure 6 depicts this condition.

In addition, it was observed that steel plates thicken than 3 mm separated from the beam at failure. Improving the quality of concrete appeared to prevent this loss of bond, and it is recommend that concrete C 30 or better should be used in the beam.

In conclusion, an experimental work has shown that strengthening or supporting reinforced concrete beams by gluing a steel plate underneath is an economical and effective way of improving the structural capability. This method is especially useful to repair damaged structures.

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